

Skills and Competencies for Resilience in Manufacturing Systems: A Systematic Literature Review

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Abstract— *The manufacturing industry operates in a constantly changing environment, whether internal or external. Revolutionary shifts in demand and technology are becoming more common. As a result, organizations must be prepared to absorb or mitigate the impact that these changes may have on their outcome, thereby becoming resilient. The aim of this study is to identify which skills and competencies manufacturing companies must develop to become resilient and resist these sudden changes. In order to achieve the proposed goal, this article conducts a systematic literature review. Two databases, Science Direct and SpringerLink, were searched, as well as articles published at the Resilience Engineering Symposium between 2015 and 2020, using the search term "resilience engineering in manufacturing." A total of 64 relevant articles were obtained. The analysis of the articles yielded 23 skills and competencies that companies use to be resilient, with organizational flexibility being the most mentioned skill. As a result, these skills were classified using the four theoretical skill profiles for a resilient system (monitor, anticipate, respond, and learn). There was practically a balance between the four skills mentioned by the authors in the articles, with a higher tendency for the ability to respond to variability, interruptions, disturbances, and opportunities presented in a manufacturing system.*

I. INTRODUCTION

Organizations or manufacturing systems are currently embedded in environments that may undergo transformations. Changes can occur within or outside of the system, with varying degrees of impact and frequency. A minor impact can have a significant impact on an organization, and it must be prepared to deal with the consequences to avoid losses, errors, or failures ^[1]. Similarly, adverse, or unexpected external events can disrupt the system's normal operation, impairing the expected outcome. These events could include pandemics,

terrorist attacks, natural disasters, and economic downturns ^[2].

Manufacturing systems are increasingly being forced to deal with the consequences of these unfavorable events on their processes. This is justified by the current historical period's frequent and rapid changes in technology and demand. As a result, organizations have looked for ways to adapt to these events to absorb or mitigate their negative impact ^[3].

Because of the incorporation of organizations into this dynamic environment, people engaged in system activities

are frequently challenged to adapt in order to maintain productivity at acceptable levels of performance. However, if these activities are not properly monitored, they can jeopardize security or the company's own operations ^[4].

This problem arises because managers are unaware of the information pertaining to the execution of these activities. As a result, an organization can become more resilient once all managers at all hierarchical levels have access to information on how activities are carried out, providing the necessary resources for people to adapt and make decisions in unexpected situations, thereby maintaining the safety flow of effective production ^[5].

Resilience in manufacturing systems can be defined as their ability to withstand the effects of adverse events while retaining their structure. This concept also includes the ability to reorganize, reconfigure, restructure, and reinvent in response to a disruption ^[6].

According to the above-mentioned concept, systems that move from failure to success, or from loss to gain, by combining aspects of robustness and agility ^[1], acquiring skills to respond to events, monitoring their current state, predicting future threats or opportunities, and learning from their signs of weakness or through past experience, are considered resilient ^[7]. Traditional production systems are resistant to changes imposed on their initial state by internal or external factors. Resilient systems, on the other hand, lack this resistance, allowing them to respond to unexpected events more quickly and effectively ^[8].

Resilience can best be understood through the four skills required for a system to be considered resilient, namely: responding to events, monitoring developing events, anticipating future threats or opportunities, and learning from past mistakes and successes. Therefore, Resilience Engineering (RE) is a discipline that composes the way these four skills can be established and managed ^[7].

Resilience Engineering emerges as a response to the environment in which organizations operate, which is characterized by an increasing level of complexity and uncertainty, as well as a need to devise new strategies to deal with these uncertainties. To that end, it provides tools for proactive risk management as well as inherent knowledge of system complexity and variability ^[9].

RE evolved from studies with different emphases, but with a common socio-technical approach that views humans and artefacts (physical and organizational) as equal agents in the system's performance. The proposed RE techniques were designed to map the interactions of agents in a complex system. One of these methods is the Functional Resonance Analysis Method (FRAM), which first saw use in aviation ^[10]. One of the most researched

lines currently proposes the use of FRAM to describe the differences between work-as-imagined and work-as-done ^[11].

Therefore, the purpose of this article is to provide an answer to the following research question: What are the most used skills and competencies to promote resilience in manufacturing systems?

This article contains five sections, the first one is the introduction, the second section describes the methodology used, and the third section describes the results of the systematic literature review. The fourth section contains the analysis and discussion of the findings. Finally, the fifth section presents a summary of the main findings and recommendations for future research.

II. METHODOLOGY

The methodology consists of a systematic review of the literature on the topic of manufacturing resilience, as well as an analysis of selected articles based on that review. These two steps are explained in detail below.

2.1 Application of Systematic Literature Review

The objective of conducting a literature review in research is often to allow the researcher to map and evaluate the existing intellectual content, which will then lead to a research question. Classical reviews have been criticized for including only authors from a certain area, chosen for inclusion based on the writer's implicit biases, and for a lack of critical appraisal. Systematic reviews, on the other hand, present a repeatable procedure and transparent scientific processes that aim to minimize or eliminate biases through an exhaustive literature review that allows the reviewers' decisions to be traced ^[12].

The systematic literature review of this study consists of three steps: defining the parameters used in article selection, selecting databases to consult, and analyzing the articles that were chosen. The research done for this study was restricted to articles in the English language based on the keyword "resilience engineering in manufacturing." The research comprised articles published between 2015 and 2020, including articles from the event known as "Symposiums of Resilience Engineering".

Following the principles of a literature review ^[13], the keyword used could appear in the title, abstract or scope of the articles. As previously stated by the authors, the term "resilience" cannot be used alone because this concept is investigated in various fields such as psychology, sociology, and economics, resulting in a high number of studies which do not represent the theme of the current study.

Books, theses, dissertations, and other event articles were not considered for analysis. Only articles dealing with the theme of resilience in manufacturing systems were considered.

The databases chosen for the survey of articles were Science Direct and SpringerLink, as they were used in previous studies of the same nature. The Science Direct database search resulted in ten magazines and journals: Journal of Cleaner Production, Procedia Manufacturing, Procedia CIRP, IFAC – Papers online, Construction and Building Materials, Procedia Engineering, Renewable and Sustainable Energy Reviews, Safety Science, Science of the Total Environment and Technological Forecasting and Social Change. 82 articles on the subject were obtained from these journals.

Articles from the Administration area were used as a filter in SpringerLink's research, yielding a total of 159 publications on manufacturing resilience. There were 116 productions found in publications related to the Resilience Symposium in 2013, 2015, and 2017, the event takes place every two years. The 2019 proceedings were not available at the time of this research.

As a result, a total of 357 articles were obtained. When double publication is considered, this number falls to 345. The title and abstract were read, filtering these publications to 92 articles that could be submitted for analysis. The preliminary reading yielded 54 publications; however, 10 more articles were added as references in other articles, resulting in a total of 64 studies. Figure 1 depicts this procedure.

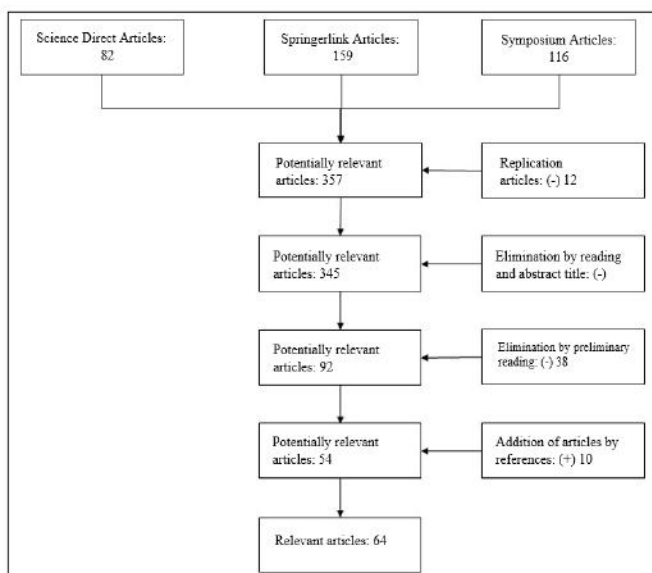


Fig. 1: Representation of the survey process

2.2 Analysis of Selected Articles

The above-mentioned aspects were analyzed in a subsequent stage. In addition, techniques for measuring or quantifying resilience in these systems are presented. Subsequently, these results are discussed with the aim of identifying the importance of resilience in systems and its difference among other concepts present in the literature. The articles were categorized into one of four categories developed by the authors of this study:

- 1 - Articles that present skills and practices for promoting resilience.
- 2 - Articles that present techniques and practices for defining and promoting resilience in organizations' suppliers.
- 3 - Articles that quantify the value of resilience, measuring it.
- 4 - Theoretical articles without presentation of practical work.

III. RESILIENCE APPROACHES

This chapter discusses the various approaches to resilience and how they are applied to manufacturing systems as well as processes that aid or support production.

3.1 General Conceptualization of Resilience

In material science, resilience is the ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading, allowing the recovery of that energy that has been accumulated. The property associated with this process is the modulus of resilience, which is the deformation energy per volume unit required to tension the material from an unloaded state to its resistance to flow. A uniaxial tensile test can then be used to calculate or measure the resilience of a given material [14].

In health and medicine, resilience is defined as the ability to maintain or recover mental health following adversity. According to the authors, the definition of resilience in this context varies from one area to the next, each conceptualized in its own way. They all, however, tend to converge on a central point, which is aimed at identifying how some people manage to overcome adversity without suffering negative physical and mental consequences [15].

The concept of resilience can be extended to organizational systems, specifically manufacturing systems, which is the focus of this study. The difference between analyzing an organizational system and analyzing an individual, piece of equipment, or material is that the

organizational system has many variables and interactions, each of which can have a negative or positive impact on it. The study of these interactions began in the Middle Ages when alchemists sought ways to convert materials into gold. Despite their failure, they discovered several properties of the materials and, most importantly, the significance of the interaction of the processes. As a result, resilience in a manufacturing system is the system's ability, given the various interactions that act on it and the interactions of its actors, to support changes in the environment and resize or restructure itself while ensuring the achievement of results ^[16].

3.2 Definition of Resilience in Productive Systems

The articles examined in this study present different concepts on resilience. These concepts vary depending on the type and location of the resilience being studied. As a methodological constraint, the resilience studied is that of manufacturing or production systems.

When it comes to manufacturing systems, it is possible to conceptualize resilience as a quantitative measurement that combines both a system's robustness and its ability to quickly restore capacity following the occurrence of a disruptive event ^[17]. Some authors agree with this definition ^[18], adding that resilience is a system's ability to withstand potentially high-impact interruptions, as defined by its ability to mitigate or absorb the impacts of interruptions while recovering quickly and returning to normal conditions. In addition, the use of redundancy and flexibility allows a system to resume operation following failures, component failures, and so on. This capability is critical in the design of engineering systems, operating systems, and life management systems in the face of disruptive and adverse events ^[19].

In a more specific context, such as manufacturing and assembly systems, resilience is defined as the system's ability to deal with all types of changes. One property that contributes to resilience is robustness. It enables a system to function despite external and internal disturbances, which is an important property because it promotes an appropriate response to environmental turbulence ^[20].

Another view tries to integrate some lean concepts as well. The authors define resilience as the ability to resist or quickly recover from unexpected interruptions. For this, the system or production line must be robust and capable of anticipating disruptive events, as well as having a control strategy in place to mitigate the impact if the event occurs. This concept considers unexpected events such as resource shortages and quality loss, both of which stem from the lean approach ^[21].

Sanchis and Poler ^[22] propose a concept of resilience divided into three different perspectives. The first takes a

proactive approach, arguing that organizations must be prepared to anticipate and mitigate the negative effects of outages. The second represents a reactive perspective, which includes resilience, in which the company attempts to restore operations after disruptions occur. The third vision proposes a continuous vision, that of adaptive capacity, which can be defined as an organization's ability to adjust and adapt to a changing environment.

3.3 Resilience in Ergonomics and Safety Engineering

Resilience Engineering is a security approach or philosophy that focuses on the prevention, detection, and management of disturbances before, during, and after they occur, while also incorporating human factors. The authors propose a model that incorporates factors that promote a resilient environment, such as system complexity, worker age, worker commitment, preparation, and experience, among others ^[23].

Shirali and Nematpour ^[24] and Gattola, et al. ^[25] agree with the previous authors that resilience includes the ability to anticipate and manage risks before they become serious threats to the operation, as well as the ability to survive a situation in which the operation has been compromised. RE strives to clarify how the organization creates security to determine when the model needs to be reviewed. In a similar vein, England ^[26] defines resilience as the amount of time required to regain equilibrium following adversity.

Other vision of resilience is the one focused specifically on workers and their well-being. According to the authors, RE is built on four pillars that take into account all levels of the organization: responsiveness, critical development monitoring, anticipating threats and opportunities, and learning from past experience. The RE seeks to correctly identify and value behaviors and resources that contribute to the responsiveness of systems. Thus, the authors propose monitoring the well-being of workers as an indicator of system performance, since healthy workers are associated with a healthy system, increasing adaptability and resilience to unexpected events ^[27].

Pan, Su, and Zhou ^[28] argue that a resilient installation leads to a resilient community, particularly in security. The resilience of facilities is related to disaster management, as it is necessary not only to respond to disasters, but also to intentionally develop the capacity to absorb the effects of these disasters. This is a facility and its occupants' capability. The involvement of occupants is also important because when an adverse situation occurs, the group must respond as a whole. To promote engagement of the occupants, the authors created a disaster training alternative game.

3.4 Other Definitions and Applications of Resilience

Cybersecurity is defined as the ability of systems to be immune to threats, and cyber defense is defined as the ability of systems to successfully resist cyber incidents. Thus, resilience is defined as the "sum" of cybersecurity and cyber defense. In this case, it aims to preserve the continuity, reliability, and safety of activities ^[29].

In addition, it is possible to apply the concept of resilience to product development, stating that resilience must ensure the availability of "post-surprise" options, assuming that surprises in the process are unavoidable. In his work, the author develops a holistic approach, integrating risk-based thinking with resilience, and applying it in product development, claiming that risk management and resilience are disciplines that complement one another ^[30].

A different approach is the one that focus on safety indicators. According to the authors, resilience recognizes that security reviews that focus solely on negative events make it difficult to fully comprehend the process. Based on that, they define it in three dimensions: risk awareness, responsiveness, and support ^[31].

Navaratne ^[32] extends the concept of resilience to the area of material selection, stating that the resilience of a system can be increased by the adoption of certain practices, methods, or the use of certain materials. In his work, the author tested various packages of noodles, a common emergency food. He stated that by locating suitable material, food security resilience could be improved, particularly in the event of a disaster.

3.5 Quantification and Measurement of Resilience

Resilience can be quantified and calculated. The authors, here, propose a model for calculating the value of resilience in manufacturing plants. The proposed model consists of seven steps: 1. Map the process flow; 2. Build the process capability block diagram; 3. Build the global network of reconstruction activities; 4. Define the damage scenario; 5. Calculate the initial loss of capacity; 6. Determine the capacity recovery function and 7. Determine economic loss. The model is used to determine the capacity recovery curve and economic loss for any predefined damage scenario caused by disruptive events that affect manufacturing facilities. This model generates an estimate of the value of the system's resilience ^[33].

Furthermore, Pavlov and Zakharov ^[34] propose a method for quantifying supply chain resilience. The authors created an original model based on the concept of a hypergraph of production processes as well as the functioning of its differentiation. The proposed resilience

indicators are structurally functional and structurally technological.

Focusing on safety, a performance indicator model was developed that can represent early warning signs of system functional criticism. The authors chose to collect environmental data through games, experimenting with GREWI (Resilience-based Early Warning Indicator Method), a new method based on gamified data collection. This approach aims to encourage workers' engagement in workplace safety. In the end, it was possible to measure workplace resilience ^[31].

Schattka, Puchkova, and McFarlane ^[35] developed a method for assessing a production system's performance in the face of process interruptions and determining the overall effective level of resilience. The authors used an Artificial Intelligence-based Operational Research technique to perform a stochastic simulation, generating an optimization method and a resilience score.

Kammouh, Gardoni and Cimellaro ^[36] introduced an approach to assess the time-based resilience of engineering systems through indicators. A Bayesian Network (BN) approach is employed to deal with the relationships between indicators, however, due to the dynamism of engineering systems, the temporal dimension is approached using the Dynamic Bayesian Network (DBN). DBN extends the classic BN by including a time dimension, allowing variables to interact at different stages of time. It can be used to track the evolution of a system's performance based on data collected in a previous step. This allows you to predict the state of resilience of a system through its initial condition. A DBN-based mathematical probabilistic framework is developed to model the resilience of dynamic engineering systems.

3.6 Techniques and Practices that promote Resilience

The use of redundancies and flexibility can improve a system's resilience. In industries and hospitals, for example, system redundancy is very common. It is a reserve element that enters the field if the primary one fails. One example is the use of backup generators in hospitals in the event of a power outage. The authors also claim that having parallel machines in a system makes it more resilient because, in the event of a failure, the backup machine replaces the one that is stopped. Flexibility, on the other hand, represents how easily a system can readjust when adversity occurs ^[18].

Azadeh, Roudi, and Salehi ^[23] reinforce this idea by stating that flexibility, redundancy, and adaptability are variables that can be used to promote and measure resilience. The authors also emphasize that some customer-related variables, such as integrity, benevolence, capacity, and predictability, can be used for this purpose.

The authors assess the resilience of their suppliers by using additional cost and delivery time variables, concluding that adaptability is the most important variable in this regard.

Karl et al. [37] demonstrates ten practices identified in the literature for promoting resilience in their study: sustainability, agility, redundancy, flexibility, visibility, sharing of resources or information, robustness, sensitivity, risk management culture, adaptability, market position, risk control, public-private partnership, and supply chain network design.

Sharing information in an organization's supply chain promotes resilience by reducing uncertainty and risk. Li et al. [38], confirms this point by demonstrating through experiments that sharing information reduces the amount of backordering or reprogramming.

Another technique used to promote system resilience is found in the work of Ljasenko, Lohse, and Justham [39], who replaced fixed automation systems with mobile robots. The study sought to determine whether this change influenced the occurrence of urgent orders, the arrival times of fluctuating products, and variations in the production mix. The results revealed that the robots were more beneficial to the system.

Righi and Saurin [40] define a wide range of elements that interact dynamically to promote resilience. The authors demonstrate this by stating that making processes and results visible, as well as encouraging diversity of thought in decision making and understanding the difference between prescribed and actual work, are all actions aimed at promoting organizational resilience. Saurin et al. [41] declare that actions that promote resilience would result from the scenario-based training itself, because it was designed to directly dialogue with the four fundamental skills that a system must have to be resilient: responding, monitoring, learning, and anticipating

Training and guiding workers to improve working conditions is also considered a practice to generate resilience [24]. Ray-Sannerud, Leyshon and Vallevik [27] emphasize that healthy workers are associated with a healthy system. According to Patriarca et al. [31], using heuristic techniques in the manufacturing process can also help to increase resilience. Monitoring system configuration on a regular basis and encouraging cooperation among stakeholders in a supply chain are also ways to improve it [42], [20].

IV. PRESENTATION AND DISCUSSION OF FINDINGS

A review of the literature that supports the adopted methodology was presented in the previous chapter. The

results of the tabulation analysis, as described in the methodology, are then presented.

4.1 Analysis of Skills and Competencies of a Resilient System

As described in Chapter 2, the analyzed articles were classified into four categories. Figure 2 depicts their positions in relation to the total number of studies examined. It is possible to verify that most of the articles analyzed bring some practice or skill related to resilience.

In category 1, it is possible to verify that each author defines and applies the concepts of resilience in different ways. All concepts, however, have the same foundation, which is the ability of a system to mitigate or absorb the effect of a disruptive event and quickly recover to normal conditions. Some authors continue to categorize resilience into two categories: proactive resilience and reactive resilience. In some studies, continuous resilience is also defined as a third perspective, which is related to the adaptive capacity of a system [17], [22].

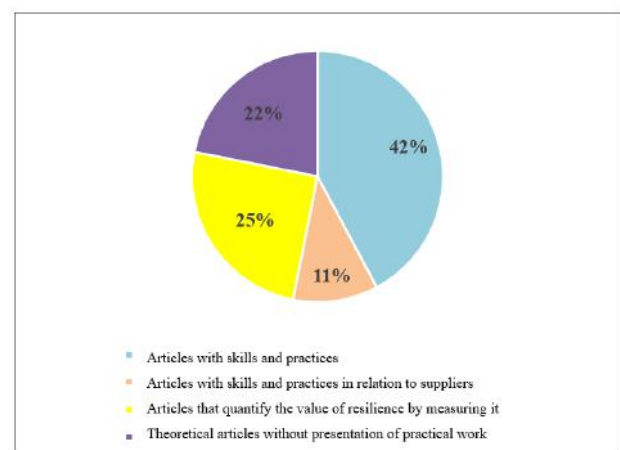


Fig. 2: Article's positions in relation to the total number of studies examined

Finally, all practices, skills, competences, and techniques that promote system resilience, particularly in manufacturing systems, were considered to determine which are the most studied in the literature or the most frequently used by organizations. This analysis identified a total of 23 skills and competencies. Table 1 presents all the skills, as well as the relative frequency of each one.

Table 1: Skills and competences identified in the articles

Skill/Competencies	Absolute frequency	Relative frequency
Flexibility	8	29.63%
Monitoring of impacts and risks	5	18.52%
Anticipation of impacts and risks	5	18.52%
Redundancy	5	18.52%
Adaptability	5	18.52%
Training	4	14.81%
Collaboration	4	14.81%
Diversity of thoughts	3	11.11%
Agility	3	11.11%
Robustness	3	11.11%
Visibility	2	7.41%
Sustainability	2	7.41%
Sharing information	2	7.41%
Market position	2	7.41%
Social responsibility	2	7.41%
Safety culture	2	7.41%
Physical infrastructure	1	3.70%
Sensitivity	1	3.70%
Decentralization	1	3.70%
Reengineering	1	3.70%
Trust between members	1	3.70%
Responsiveness	1	3.70%
Learning	1	3.70%

The analysis of Table 1 reveals that flexibility is the most studied and cited skill for promoting resilience in manufacturing systems. Flexibility can be defined as the ability of a system to restructure itself in response to the occurrence of a specific event, such as the manufacture of a new product. Extending this concept of flexibility to the supply chain, it is defined as a chain's ability to adjust in response to the needs of its partners and environmental conditions in the shortest amount of time possible [39], [37].

Following flexibility, four other skills are listed as the second most important for promoting a resilient system: risk anticipation and monitoring, redundancy, and adaptability. Adaptability is a similar concept to flexibility, but it is defined as the ability to assemble an adequate structure to adapt to new conditions and goals. As previously stated, the use of redundancy is defined as the use of backup equipment or systems that activate when the primary one fails. Finally, the culture of anticipating and monitoring risks stems from the safety and project sectors and is defined as the ability to anticipate events and monitor them over time [20], [26].

Training and collaboration skills are ranked third on the list. Training is the process of guiding employees on how to behave in disruptive situations so that they do not panic. If workers are well-organized, they will be able to successfully absorb or mitigate an adverse event. Collaboration encompasses not only interactions between employees, but also interactions between businesses and their customers, its suppliers, shareholders, and so on [24], [42].

Finally, the ability to agility and sturdiness are present in fourth place. Agility is defined as the ability to respond quickly to a disruptive event or, in the case of the supply chain, a change in offer and demand. Robustness, on the

other hand, is defined as a system's ability to withstand or absorb the impact of a negative event [37].

According to Wachs et al. (2015) [13], a system has four macro basic skills to be considered resilient: Monitor, Respond, Anticipate and Learn. As a result, you must constantly monitor for disruptions and threats. Anticipate future changes in the environment that could affect the system's ability to function. Respond to frequent disruptions and threats quickly and efficiently and learn from past mistakes and successes [43].

Figure 3 depicts the categorization of all 23 skills identified in Table 1 as belonging to one of the four macro skills of a resilient system. Based on the four previously mentioned criteria, each skill was rated only once. By analyzing the graph, it is possible to conclude that answering is the most studied macro skill, or most mentioned by the authors, followed by anticipating, monitoring, and learning.

Knowing what to do and how to respond to regular and irregular variability, interruptions, disturbances, and opportunities is referred to as the macro ability to respond. Responding also encompasses the assessment of the situation. The author also states that this ability can be divided into two strategies: proactive and reactive. Proactive refers to anticipating potentially destructive situations and defining the use of solutions, whereas reactive refers to generating, creating, inventing, or deriving solutions [43].

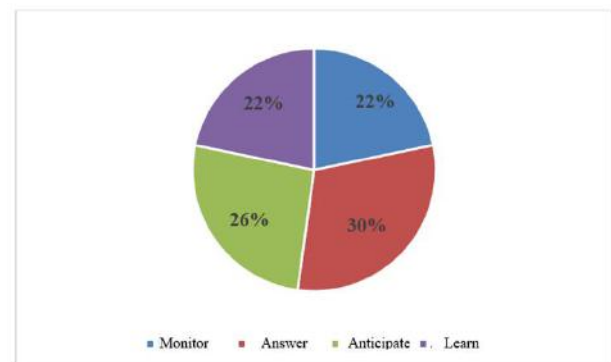


Fig. 3: Classification of skills according to macro skills

Anticipating means anticipating events, threats, and new opportunities for improvement in the future, such as potential changes, disruptions, pressures, and their consequences. Anticipating also entails giving yourself enough time to reflect on the project to identify and recognize potential issues [5].

Monitoring refers to knowing what to look for, or how to monitor what is or could become a threat in the near future that will require a response. Monitoring should

include both what happens in the environment and what happens within the system. Learning is also defined as a change in behavior as a result of an experience. Only by learning from past performance can future performance be improved. ^[43]

4.2 Analysis of the Quantification and Measurement of Resilience

According to the articles reviewed, 25% of them proposed models, methods, or ways to quantify or measure the resilience of a system, supplier, or medium. A summary of the main methods used to assess resilience is provided below.

- a) The vulnerability and resilience of suppliers can be used to estimate their resilience ^[44];
- b) Resilience can be calculated using a capacity loss and recovery function in conjunction with an economic loss function ^[33];
- c) It is possible to estimate a resilience value by considering some of the skills discussed in the previous section ^[23];
- d) A resilience value for the system was estimated using a hypergraph of production processes and their functioning and differentiation ^[34];
- e) Use process safety indicators for complex socio-technical systems, to create an early warning of failures and system resilience ^[31];
- f) Three metrics can be used to quantify resilience: performance loss, performance restore time, and total underperformance time ^[35].

4.3 Analysis of Supplier Resilience

Suppliers are an important part of a manufacturing system because a lack of supply for the organization can cause a variety of problems, so a supplier analysis is required. The analysis of the selected studies also brought criteria to define the resilience of suppliers, having their resilience measured or estimated based on integrity, benevolence, predictability, cost, and delivery time, as seen in some of the studies, for example.

Experiments by Li, Pedrielli, Lee, and Chew ^[38] demonstrated that sharing information with suppliers really helps to encourage supply chain resilience in terms of reducing backorder quantity and duration when destination inventory levels are specified.

In addition, Hosseini, and Khaled ^[44] identify eight contributors to supplier resilience in their work: surplus stock, location separation, contracting of support suppliers, robustness, reliability, forwarding, reorganization, and restoration. The set method was used to analyze and classify the data. The most important enablers of supplier

resilience were identified as robustness, reliability, and redirection.

Parkouhi and Ghadikolaei ^[45] add to the previous authors' findings by claiming that a supplier is more resilient if it ranks higher in terms of price variation, vulnerability, capacity limit, capability limit, visibility, raw material acquisition difficulties, and on-time delivery.

Chen, Hsieh, and Wee ^[46] define the following criteria for identifying resilient suppliers: Finance, Quality, Delivery, Relationship, Service, Technology and Product, Supply and Infrastructure Installation and Market Reputation, Assets and Infrastructure, Management and Organization, Corrective Action Effectiveness, Conflict Resolution and Problem Resolution Capabilities.

V. CONCLUSION

Organizations are increasingly embedded in a context of constant change because of the dynamic nature of the environment. The study of resilience aids these organizations' adequacy and survival. Technology is becoming increasingly advanced, and as a result, demand, products, and services are rapidly changing. As a result, companies must be prepared to be always adaptable to the environment and to the market.

The definitions of resilience presented in this article, which vary depending on the system used, as well as the strategies for promoting them, enable this study to pave the way for understanding and maintaining resilience in these systems. Operators in these systems can also combine the various strategies presented in this article to tailor them to their organizations' needs.

The purpose of this article was to identify the skills and competencies needed for a system to be considered resilient. A systematic literature review enabled the identification of some concepts of resilience and how they are addressed in systems, particularly manufacturing systems.

The analysis of 64 articles resulting from research conducted in two databases and a Symposium revealed that resilience is conceptualized in various ways, but always with the same foundation. The results revealed that for a system to be resilient, it must be flexible above all. Other important competencies discovered in the analysis for promoting resilience in the manufacturing system are related to maintaining monitoring and anticipating impacts and threats, particularly from the external environment.

The use of redundancies has also been shown to be beneficial in terms of promoting resilience. When it comes to critical systems or components, redundancy should be used whenever possible. The results indicate that it is

possible to measure resilience quantitatively, and it is feasible to convert resilience into a number for possible comparison.

This article adds to the literature in the field, primarily for the study of resilience in manufacturing systems, by introducing the key concepts and skills required for its promotion. The study had the limitation of being based on two databases and a symposium. A scope expansion is suggested for future work, allowing more evidence to confirm the results obtained here.

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